DEVELOPMENT OF THE CO_2 DIAL SYSTEM USING 1.6μm ABSORPTION BAND

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ABSTRACT

A differential absorption lidar (DIAL) system for carbon dioxide (CO_2) observation is being developed. Transmitting wavelength we selected is around 1.572μm where there is one of CO_2 absorption bands of 30012-00001. This band has superior characteristics. The absorption cross section has appropriate magnitude so that the peak wavelength can be used for the on-line wavelength. There is very few interference from water vapor. And magnitude of the absorption cross section is precisely measured absolutely.

To generate this wavelength, Cr:YAG laser, optical parametric oscillator (OPO) and stimulated Raman shifted (SRS) Nd:KGW laser systems are discussed for the transmitter. Multi mirror, fiber coupled receiving optics and detectors for both photon counting and analogue detection are also discussed. The expected accuracy by the error estimation is better than 1% up to 10km with 1000m vertical resolution and 1 hour integration time.

1. INTRODUCTION

It is very important to clarify the current status of the greenhouse gases for further prediction of and public policymaking of the global warming. Carbon dioxide (CO_2) is known as one of the major greenhouse gases such as water vapor (H_2O), tropospheric ozone (tr-O_3), chlorofluorocarbons (CFCs), sulphur hexafluoride (SF_6), nitrous oxide (N_2O) and methane (CH_4). In these gases, CFCs and SF_6 are mainly anthropogenetically generated so that the emissions can be statistically estimated from the economic activity. However, although the CO_2 is the most important gas, not only the future prediction but also the current status is not known satisfactorily since the natural source and sink is very complicated

Global atmospheric transport model is being developed as a method of understanding the global distribution and the variation of the greenhouse gas such as CO_2. The model calculates the global distribution, and also can be used to estimate the source and sink using the observed data as the constraint condition (inverse method). Three dimensional and continuous measurement of CO_2 is needed not only to validate and improve the global atmospheric transport model but also to develop the inverse method, however, information of the vertical distribution is definitely insufficient since the ground-based observation is the main method in the existing circumstances.

Lidar is thought to be one of the ideal observing methods to obtain the vertical distributions of the greenhouse gases. Continuous measurement with high vertical and temporal resolution of the CO_2 observation by lidar has advantage over other passive methods. The data taken by lidar is expected to validate and improve the model combining with the height resolved data taken by balloon soundings and aircrafts, and surface stations including high-altitude stations.

2. SYSTEM DESIGN

2.1 Requirements to the System

To validate and improve the global atmospheric transport model and use the constraint condition of the inverse method, precision of the CO_2 measurement is considered to be better than 1ppm (about 0.3%) ideally. However, measurement with 1% (about 3.6ppm) error is still very useful since the lidar data has fine vertical resolution. The vertical and temporal resolution suitable for the current models is thought to be a few km and a few hours respectively. However, in this development, goals are set to 1km vertical and 1hour temporal resolution, which fits the next generation model.

2.2 Wavelength Selection

For DIAL measurement, at least two wavelengths which have different absorption cross section are needed. There are many CO_2 absorption bands are exist between 0.7µm and 10µm and many absorption lines are contained in each band. Considering with the interference form the other atmospheric constituents such as water vapor, magnitude of the absorption cross section and its precision, and available laser wavelength, we choose the absorption band around 1.57µm (30012-00001).

Fig. 1 shows the absorption lines of CO_2 and water vapor. There are very few water vapor absorption lines around 1.57µm. Magnitude of the absorption cross section is relatively low comparing with the 2.0µm band and peak absorption of the absorption line is suitable for the DIAL measurement. This makes it possible to use the peak wavelength of each absorption line as on-line wavelength. Comparing with some proposal which use the 2.0µm band [1, 2], the error caused by the wavelength control drastically reduced since wing wavelength must be used using 2.0µm band. From the comparison between the several experimental results, including some versions of HITRAN database, absorption cross section of strong absorption lines in the R-branch of the 30012-00001 band is absolutely decided with very good accuracy which is much better than 1% [3]. The pressure shift of the absorption line is discussed in the other paper [4].

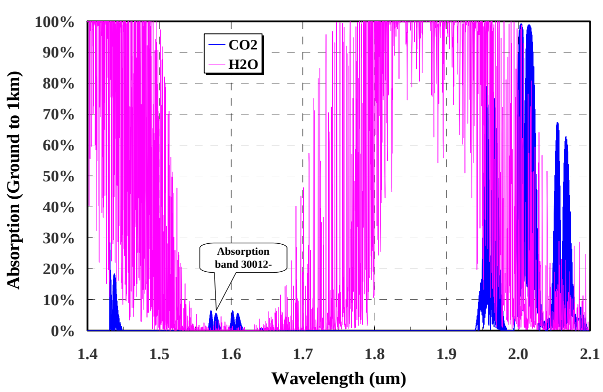

Fig. 1 Absorption lines of CO_2 (blue) and water vapor (pink) between 1.4 and 2.1µm. The selected absorption band, 30012-00001, is located in the valley of the water vapor absorption lines.

2.3 Transmitter Design

There are some lasers and/or laser systems which has possibility to use around 1.57µm. We consider three systems.

1. Cr:YAG laser.
2. Optical parametric oscillator (OPO).
3. Stimulated Raman scattering (SRS) system using the $BaNO_3$ crystal pumped by a Nd:KGW laser.

The oscillating wavelength of these three laser systems shows in Fig. 2 superimposed onto the CO_2 absorption band. The OPO system has the widest oscillating range, however, the SRS system also can be used for the CO_2 measurement.

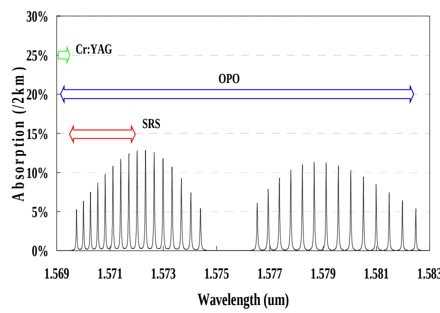

Fig. 2 Oscillating wavelength range of three laser systems and the CO_2 absorption band.

The schematic diagrams of the OPO and SRS systems are shown in Fig. 3 and 4 respectively. Both of these systems are used with an injection seeding system.

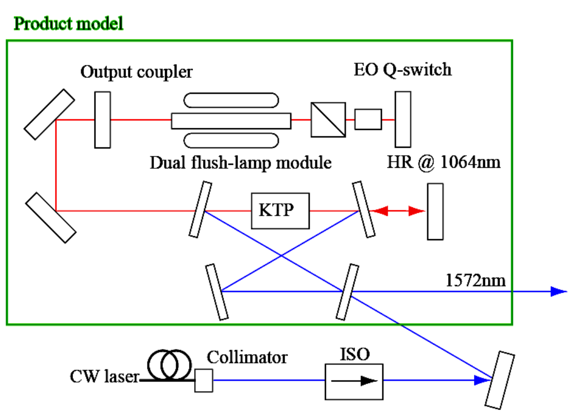

Fig. 3 Schematic diagram of the OPO system. Injection seeding system is shown in the outside of the box shown by green line.

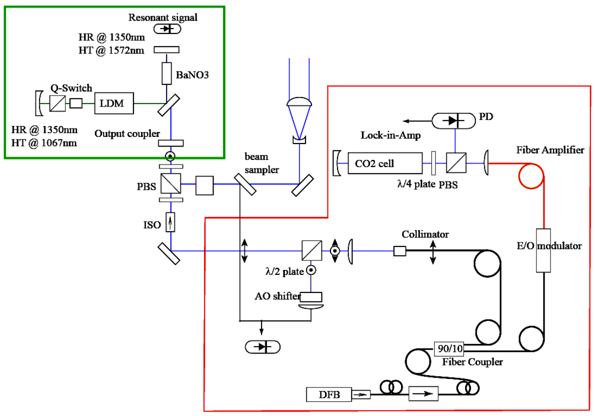

Fig. 4 Schematic diagram of the SRS system. Stimulated Raman shifter using a $BaNO_3$ crystal and the Nd:KGW pumping laser are framed in by green line. Injection seeding system including the wavelength tuning system is shown in the red line box.

These two systems will be tested to determine the better system. Detail of the laser system is discussed the other paper [5].

2.4 Receiver Design

The solid-state detectors around 1.57μm are actively involved since this wavelength is used for the optical communication system. So there is a possibility the detector is used by the CO_2 DIAL system. However, effective aperture of the detectors for communication purpose is generally narrow (50-60μm) since the optical fiber is used on the optical communication system and the diameter of the detector must fit the diameter of the fiber. Narrow diameter of the detector is one of the major problems when the detector is used in the lidar receiver system.

In general, the larger telescope diameter, the better for lidar receiver. However, the diameter of the receiver telescope is limited from the narrow detector aperture to get the practical receiver field of view. Calculated form the biggest detector aperture diameter of 200μm which can be used at 1.57μm and have high efficiency, the telescope diameter is limited to 200mm of which focal ratio, F, is 1.2. The field of view we can get is 800μrad. Also the focal depth is very thin (about 4.5μm, so that quite stable materials must be used for the structure of the system…Multi-mirror system is thought to be required to measure upper troposphere.

Schematic diagram of the receiver system is shown in Fig. 5. 6 of 200mmϕ mirrors are used for upper altitude and a 200mmϕ mirror is for lower atmosphere. All signals are delivered by optical fibers into the InGaAs APDs. Single photon countable APDs are used for upper channels and A/D APD is used for lower channel.

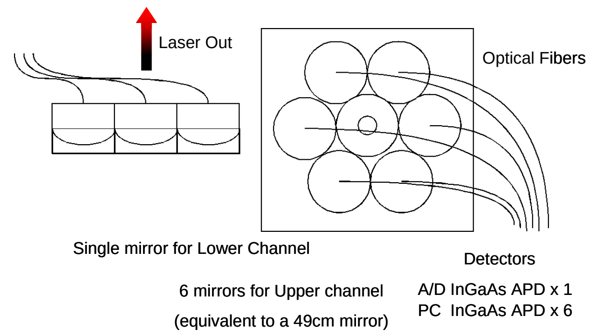

Fig. 5 Schematic diagram of the mirror allocation of the receiver system.

2.5 Error Estimation

The error analyses are executed to determine the goal of the development. The statistical error calculated by the simulation and the lidar parameters used in the simulation are shown in Fig. 6 and Table 1 respectively. Less than 1% of statistical error is expected up to 10km altitude. However, there are other causes making errors. The biggest error is thought to be caused by the temperature dependence of the absorption cross section of CO_2. Fig. 7 shows the error including the temperature dependence of the CO_2 absorption cross section. The error shown is the difference from the CO_2 density when the US Standard temperature profile is assumed. When the temperature deviation is within ±5%, the error fit into less than 1%. Even more than 5% and less than ±10%, the error is less than 1% in most of altitude range. Although the error exceeded 1%, the error can be reduced using the other temperature profile such as more realistic model and radiosonde sounding.

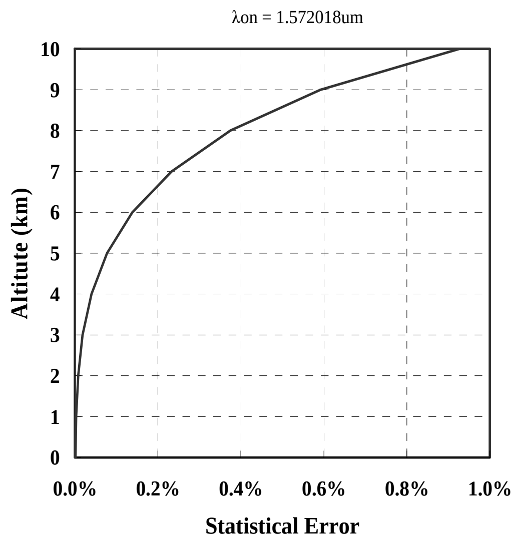

Fig. 6 Statistical error of the CO_2 DIAL.

Table 1 Lidar parameters used for the error estimation

Laser	Output	100mJ/Pulse
	Repetition	100Hz
Receiver	Telescope Diameter	50cm
	Quantum Efficiency	80%
	Noise Equivalent Power	2×10^{-14} WHz$^{-1/2}$
	Efficiency of Optics	80%
	Altitude Resolution	1000m
	Integration Time	360,000shots (1hour)

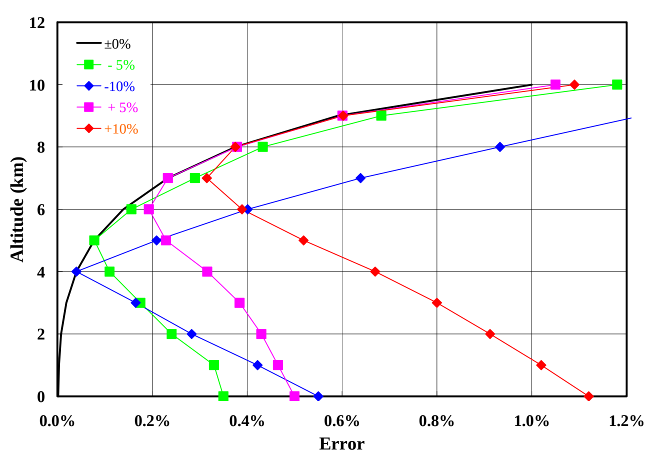

Fig. 7 Estimated error including statistical error and errors caused by the temperature dependence of the absorption cross section of CO_2.

3. SUMMARY

The CO_2 DIAL system is designed and the performance is simulated. The practical system is designed and performance, which thought to be valuable data for validation and improvement of the global atmospheric transport model and inverse method.

4. REFERENCES

1. Koch, G. J., et al., Coherent Differential Absorption Lidar Measurements of CO_2, *Appl. Opt.*, 43, 5092-5099, 2004.

2. Gibert, F., et al., 2μm Heterodyne Differential Absorption Lidar Measurements of Atmospheric CO_2 Density in the Boundary Layer, *Proceedings of the 13th Coherent Laser Rader Conference*, 105-108, 2005.

3. Fukabori, M, Private communication, 2005.

4. Sakaizawa, D., et al., The pressure shift of carbon dioxide for the on-line wavelength of 1.6μm CO_2 DIAL, *Proceedings of the 23rd ILRC*, This issue, 2006.

5. Sakaizawa, D., et al., Development of the laser transmitter of the 1.6μm CO_2 DIAL, *Proceedings of the 23rd ILRC*, This issue, 2006.

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